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(54) **BLEEDER CIRCUIT CONTROLLER**

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(52) **U.S. Cl.**

CPC ***H05B 33/0815*** (2013.01); ***H05B 33/0845*** (2013.01)

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USPC .... 315/194, 209 R, 185 R, 291
See application file for complete search history.

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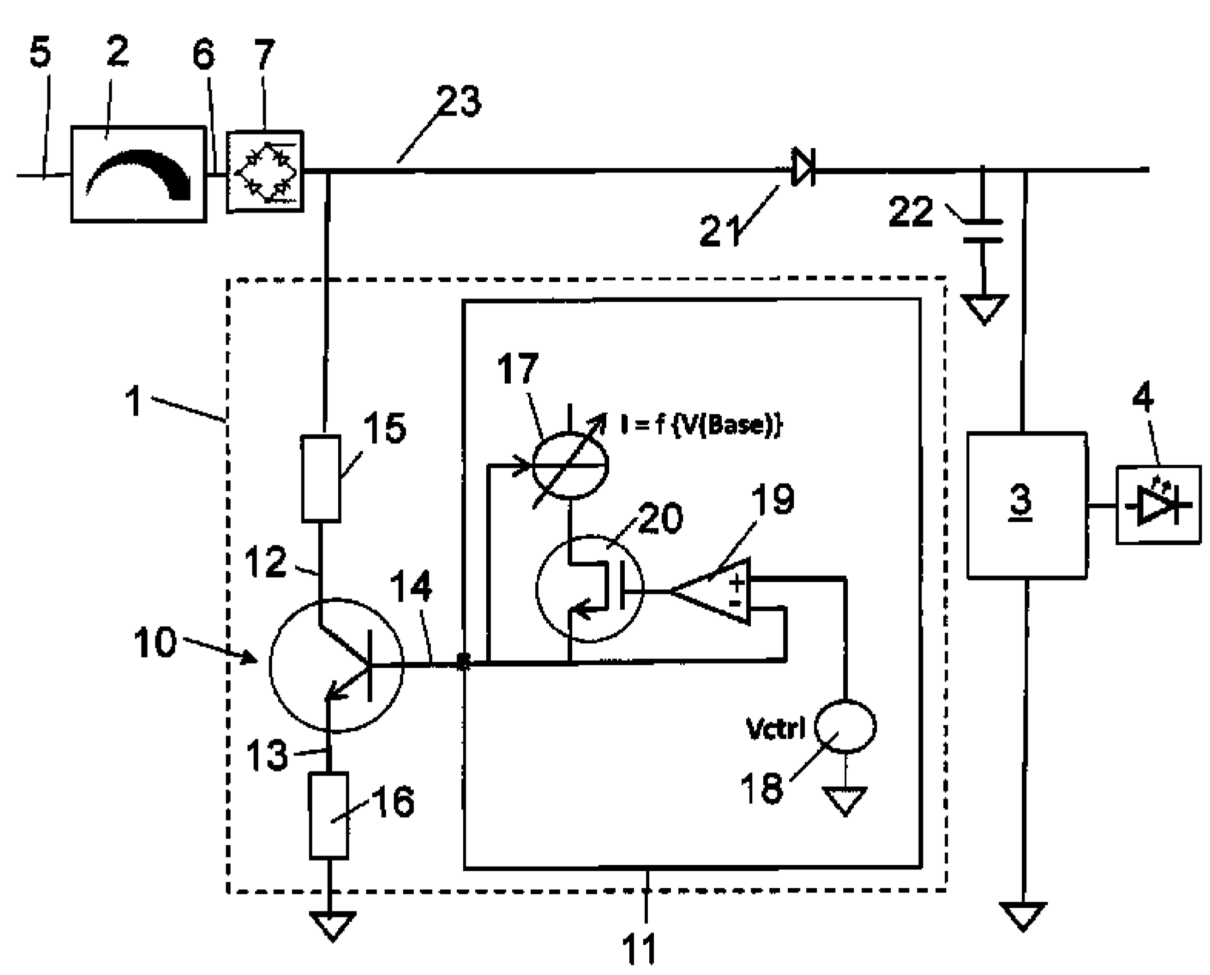
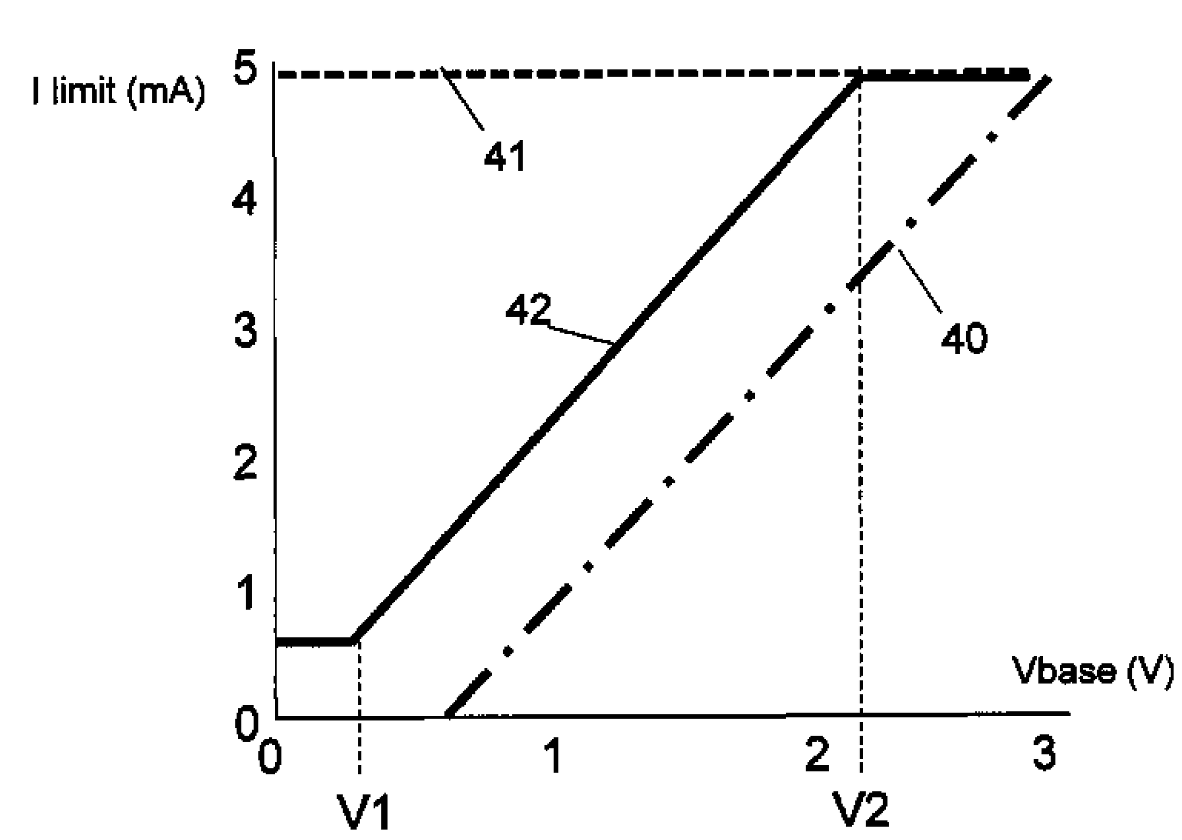
(57) **ABSTRACT**

A bleeder circuit controller (**11**) configured to control a bipolar junction transistor (**10**) having a collector (**12**) configured to be connected to an output of a phase cut dimmer (**2**) for receiving a bleed current, an emitter (**13**) for connecting to ground and a base (**14**), the bleeder circuit controller configured to generate a control signal for controlling the bleed current through the bipolar junction transistor (**10**) and measure a signal indicative of the current flow through the dimmer (**2**) and apply a current limit to a base-emitter current flow as a function of the measured signal.

12 Claims, 2 Drawing Sheets





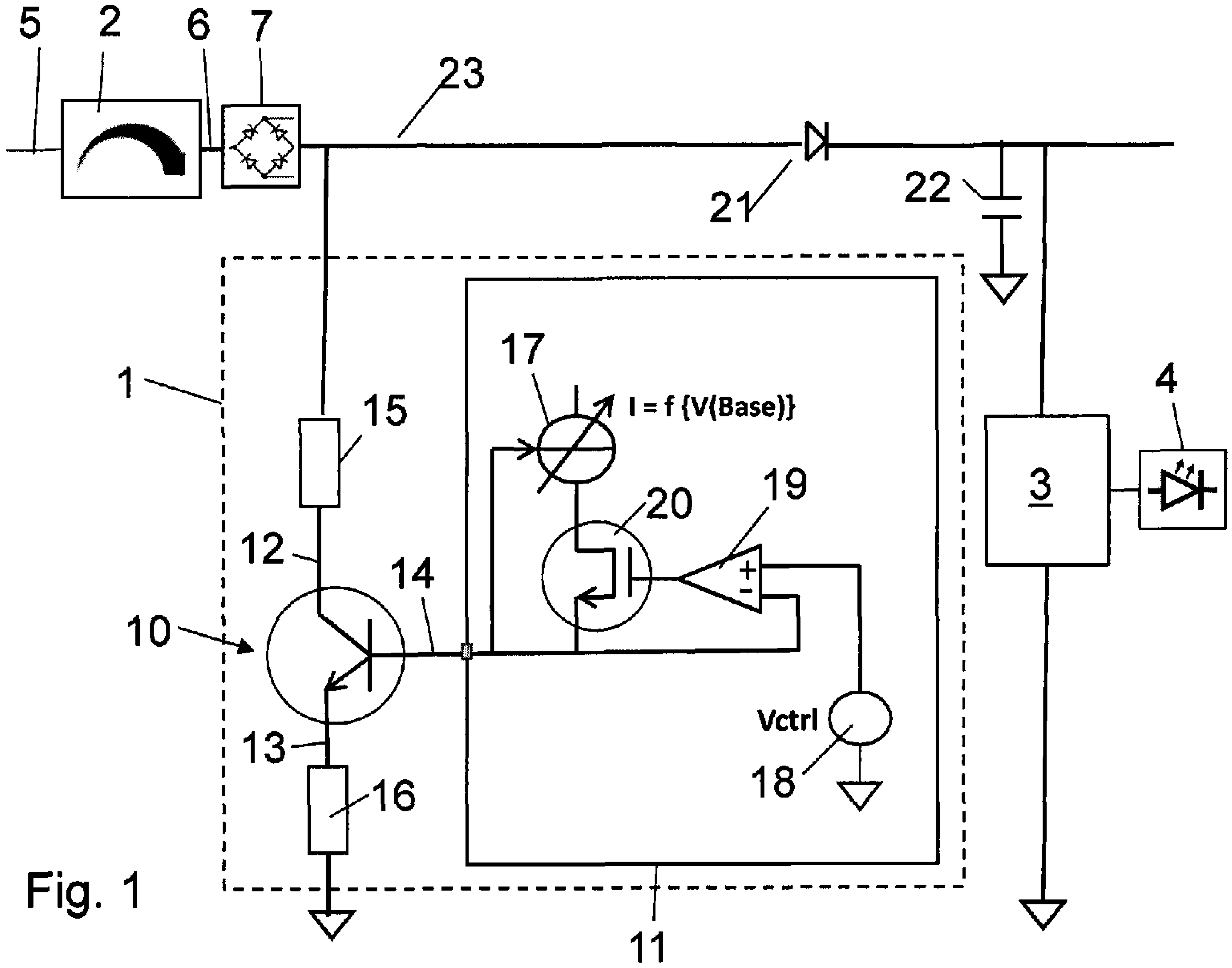
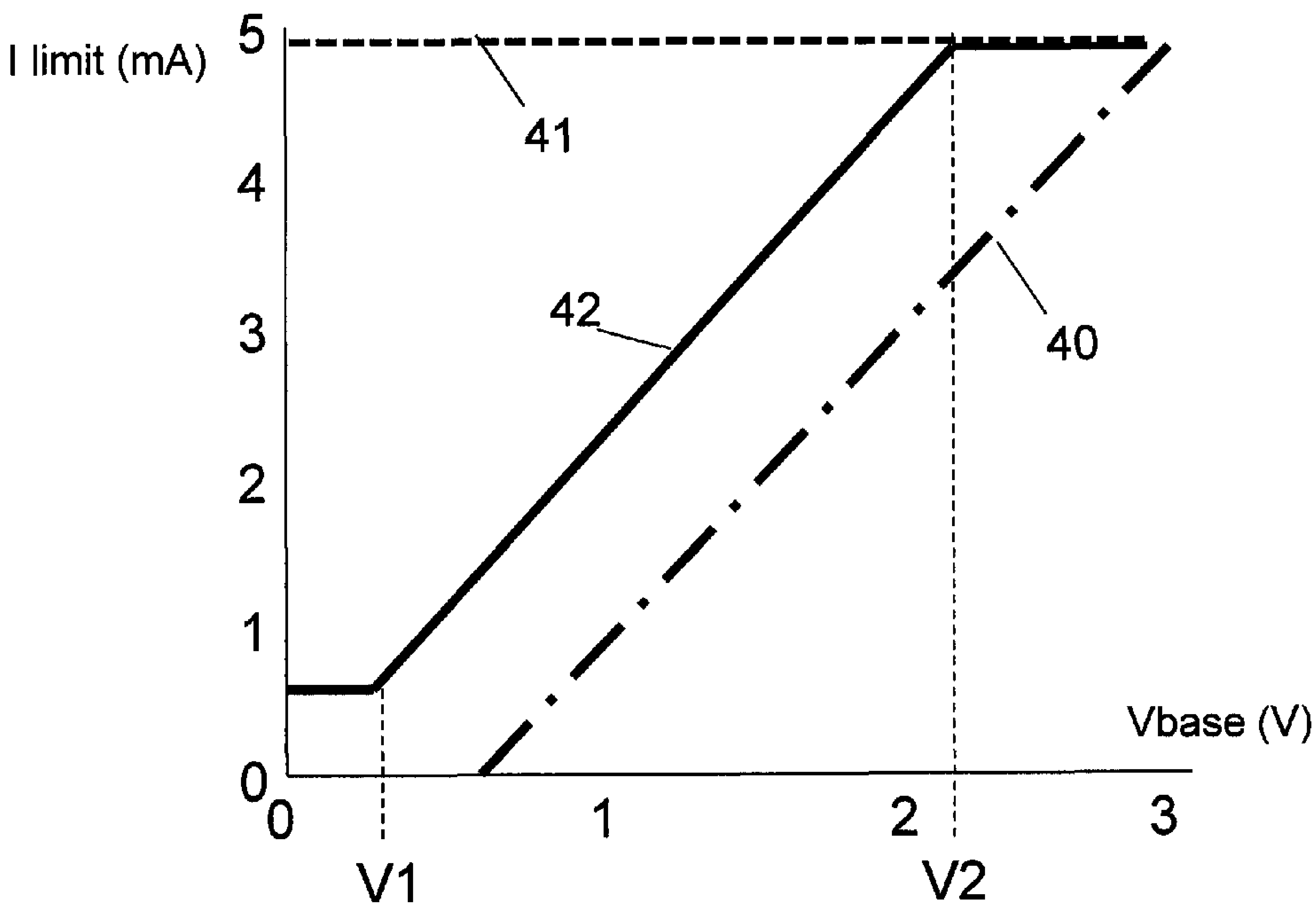

5
2
6
7
23
21
22
17
I = f {V(Base)}
4
1
15
20
19
3
12
14
10
13
Vctrl
18
16
11

Fig. 1

Fig. 3


I limit (mA)
5
4
3
2
1
0
41
42
40
Vbase (V)
0
1
2
3
V1
V2

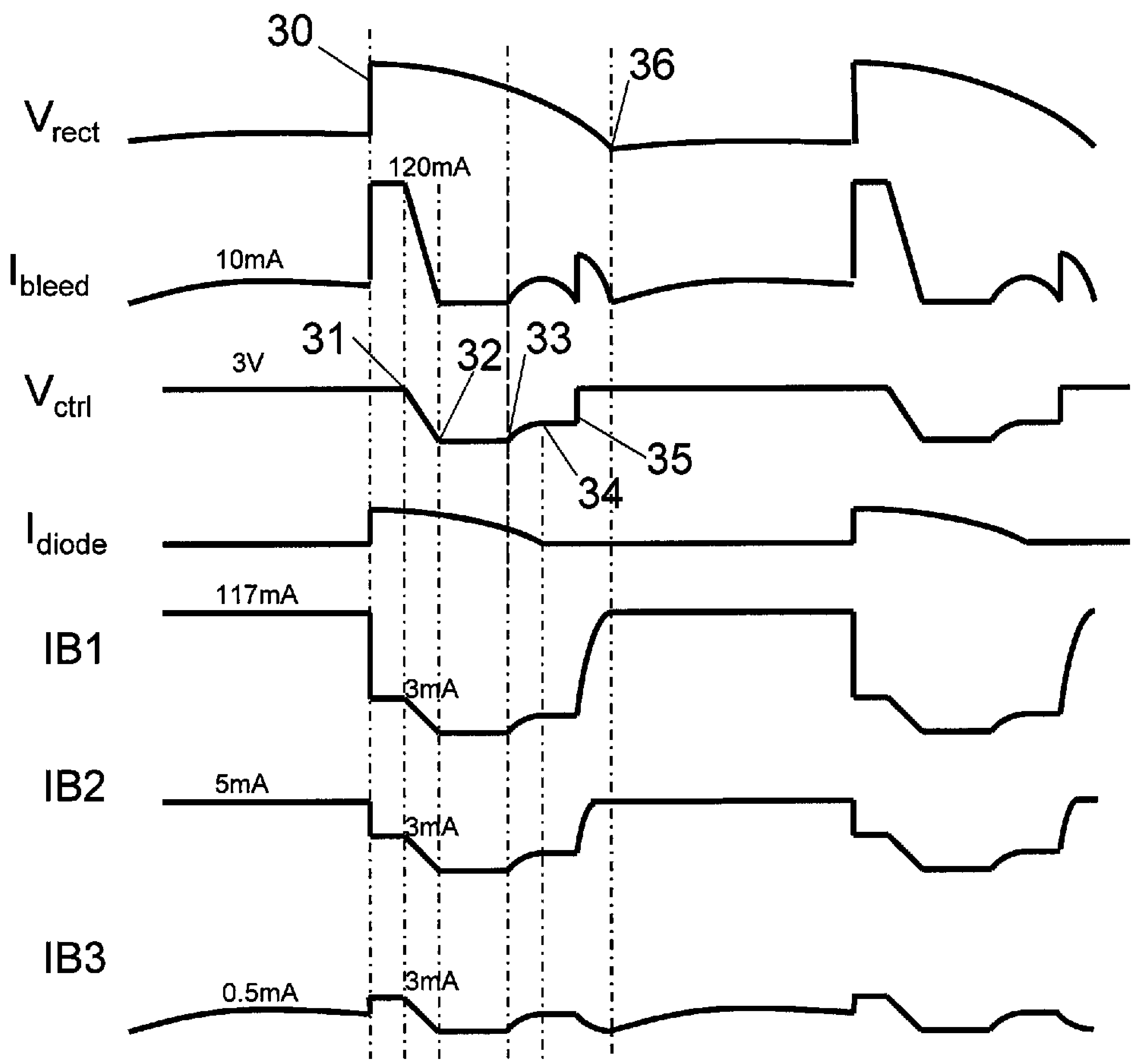

30
36
V_{rect}
120mA
I_{bleed}
10mA
31
32
33
3V
V_{ctrl}
35
34
I_{diode}
117mA
IB1
3mA
IB2
5mA
3mA
IB3
3mA
0.5mA

Fig. 2

BLEEDER CIRCUIT CONTROLLER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the priority under 35 U.S.C. §119 of European patent application no. 13199557.3, filed on Dec. 24, 2013, the contents of which are incorporated by reference herein.

This invention relates to a bleeder circuit controller for controlling a bipolar junction transistor in a bleeder circuit for use with a phase-cut dimmer. It also relates to a solid state lighting driver including the bleeder circuit controller and a solid state light including the driver and the bleeder circuit controller.

A phase cut dimmer is used to control the current flow to a load, typically for lighting applications. Phase cut dimmers typically include a triac or other switching device for periodically switching between on (conducting) and off (non-conducting) states at a predetermined phase of the applied waveform wherein the ratio of on-state to off-state provides the current flow control. Phase cut dimmers operate reliably with incandescent bulbs but a bleeder circuit may be required for operation with solid state lighting. In solid state lighting, a switched mode power supply is used to drive an LED array, for example, which has a current draw that may not operate reliably with a phase cut dimmer. In particular, a phase cut dimmer may need a minimum load in order to operate correctly. This can be an issue when connected to an efficient dimmable LED. Further, a "latching current" is required to be drawn to complete the transition from off-state to on-state. For LED lighting, a bleeder circuit may be used to pull the whole or part of this current, termed a "bleed current", required for reliable operation of the phase cut dimmer.

According to a first aspect of the invention we provide a bleeder circuit controller configured to control a bipolar junction transistor having a collector configured to be connected to a rectified output of a phase cut dimmer to receive a bleed current, an emitter for connecting to ground and a base, the bleeder circuit controller configured to generate a control signal for controlling the bleed current through the bipolar junction transistor and measure a signal indicative of the current flow through the dimmer and apply a current limit to a base-emitter current flow as a function of the measured signal.

The controller is advantageous as it has been found to reliably control a bipolar junction transistor (BJT) such that it can be used successfully in a bleeder circuit. The use of a BJT in a bleeder circuit is advantageous as they may be more cost effective than MOSFETs used in known bleeder circuits. The determination and application of a current limit as a function of current flow through the dimmer leads to an efficient controller. Thus, the BJT can be controlled such that its current sink capability at the collector adapts to the current through the dimmer to provide an efficient bleed circuit without losing significant drive current into the base of the BJT when it is operating in a saturated mode, for example when the dimmer output voltage is low, such as during the dimmer's non-conduction state. In particular, the BJT may be controlled such that it remains within a linear region of operation or on the edge of saturation and can respond to changes in current flow through the dimmer to adjust the base-emitter current limit through the BJT. Thus, the controller comprises a BJT controller.

The signal measured by the controller may comprise at least one of;

- a voltage at the base of the bipolar junction transistor;
- a voltage at the emitter of the bipolar junction transistor;
- a voltage at the collector of the bipolar junction transistor; and
- a rectified phase cut mains voltage, the mains voltage comprising the voltage applied to an input of the phase cut dimmer.

It has been found that each of the above voltages can give the controller an indication of the current flow through the dimmer, which can be used to control the limit on the base-emitter current through BJT while allowing for control of the bleed current. The voltages at the base, emitter and collector may be measured relative to ground.

The controller may be configured to control the bipolar junction transistor by applying the control signal at the base for controlling the bleed current from the phase-cut dimmer through the bipolar junction transistor. Control of the current at the base can control the flow of the bleed current from the collector to the emitter.

The controller may include a voltage source and may be configured to control said voltage source to generate said control signal. Thus, the voltage source may be used to control the BJT such that is draws an appropriate bleed current in accordance with a control profile for the particular dimmer and its associated timings.

The controller may include a current source and may be configured to control the current from the current source as a function of the measured signal. Thus, the output of the current source may be dynamically limited in accordance with the function of the measured signal.

The controller may include a switch or transistor configured to control the flow of current from the current source to the base of the bipolar junction transistor. The switch may be integrated in an integrated circuit with the controller.

Alternatively, the base-emitter current may be limited by control of a switch or controllable impedance at the emitter of the BJT. Therefore, the controller may be configured to provide a current limit control signal for controlling the switch connected to the emitter to control the flow of current from the current source to the emitter of the bipolar junction transistor as a function of the measured signal. Thus, rather than controlling the voltage or current to the base of the BJT, one may add a switching element in series between the emitter and ground to control the amount of current flowing from the controller into the base of the BJT. This is advantageous in situations such as when the dimmer current drops by such amount that the BJT would be driven into saturation or in other situations. The switch may comprise a MOS Transistor or a further BJT.

The controller may generate the control signal such that it controls the BJT to draw a bleed current comprising one or more of;

- an off-state current during an off-state of the phase-cut dimmer;
- a latching current required for a forward phase-cut dimmer to transition between an off-state and an on-state;
- a holding current required for a forward phase cut dimmer to maintain the phase-cut dimmer in an on-state once it is in said on-state;
- a discharge current for a backward phase cut dimmers to lower the dimmer output voltage low at the transition between an on-state and an off-state.

Thus, the controller may be configured to draw sufficient bleed current as required. A plurality of controllers may be provided for a BJT, each configured to detect when each of the above bleed currents is required and provide a control signal to control the BJT accordingly.

The controller may include an error determination element such as an error amplifier configured to compare the voltage of the control signal with the measured voltage at the base and control the base-emitter current flow using said comparison. The error determination element may be configured to control the current flow to the base.

The BJT may be a low voltage device when combined with a cascaded high voltage metal oxide semiconductor transistor (MOST), the collector of the low voltage BJT connected to the source of the high voltage MOST, the drain of the MOST connected to the rectified mains and the gate to a voltage source.

The base-emitter current flow limit function may comprise a first region in which the current limit increases with the measured signal between a first threshold and a second threshold. The increase may be linear although it could be any other relationship. The function may further include a second region defining a maximum current in which the current limit is held constant when the measured signal exceeds the second threshold.

The function may include a third region in which the current limit is held constant, at an above zero value, while the measured signal is below the first threshold. The measured signal may comprise the voltage at the base.

The function may be configured to limit the base-emitter current such that the controller, when in use, drives the bipolar junction transistor in a linear operation mode substantially on an edge of a saturation mode.

According to a second aspect of the invention, we provide a bleeder circuit comprising a bipolar junction transistor configured to be controlled by the bleeder circuit controller of the first aspect of the invention.

The bleeder circuit may include a user settable component, the bleeder circuit controller configured to use said user settable component to determine the maximum allowable current through the bipolar junction transistor.

The bleeder circuit may include a user replaceable limiting resistor external to the controller and in series with the bipolar junction transistor configured to, in combination with the controller, limit the maximum current through the bipolar junction transistor. The limiting resistor may be located between the emitter and ground.

The controller may be embodied as an integrated circuit (IC). The limiting resistor may be external to the IC.

According to a third aspect of the invention we provide a solid state lighting driver including the bleeder circuit of the second aspect of the invention.

According to a fourth aspect of the invention we provide a solid state light comprising a driver for powering the solid state light, the driver including the bleeder circuit of the second aspect of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

There now follows, by way of example only, a detailed description of embodiments of the invention with reference to the following figures, in which:

FIG. **1** shows an embodiment of a bleeder circuit in a solid state lighting application; and

FIG. **2** shows a series of graphs showing waveforms of a rectified output from the phase-cut dimmer, a bleed current profile, the control signal of the controller, the current flow into a driver of a solid state light and three examples of the base-emitter current flow; and

FIG. **3** shows a function of current limit vs. base voltage.

DETAILED DESCRIPTION

FIG. **1** shows a bleeder circuit **1** connected to a phase-cut dimmer **2** via a rectifier **7**. The output of the rectifier is also connected to a switched mode power supply **3** which supplies power to a solid state light **4**, comprising an LED array. The rectifier **7** is connected to the supply **3** via a diode **21** and is also connected to a buffer capacitor **22**. The buffer capacitor **22** serves to buffer input voltage for the supply **3** such that output current can be delivered continuously, and also during the mains zero crossings and dimmer non-conductive time. The diode **21** serves to decouple the output voltage of the rectifier **7** from the buffer voltage across buffer capacitor **22** such that the bleeder circuit **1** can load the dimmer with a current without discharging the buffer capacitor **22**.

In other implementations where a high power factor is desired, diode **21** may not be used and the capacitor **22** may have a lower value. In these applications, the supply **3** will only be active while the dimmer **2** is conducting and sufficient rectified mains voltage is available from rectifier **7**. It is appreciated that the power supply **3** may be designed to draw current even for low input voltage when the dimmer is not conducting but this generally leads to uncertainty and variation in the amount of energy supplied to the LED load **4** such that a stable light output cannot be guaranteed.

The phase-cut dimmer **2** comprises a mains voltage input **5** for receiving an alternating mains voltage supply and a phase-cut output **6** for outputting a phase-cut output signal as per the setting of the dimmer **2**. The dimmer may comprise a forward edge phase cut dimmer or a backward edge phase cut dimmer. The phase-cut signal is rectified by the bridge rectifier **7** and provided to the switched mode power supply **3** and bleeder circuit **1**. The bleeder circuit **1** is configured to draw a bleed current when required and of an appropriate size for reliable operation of the phase-cut dimmer **2**.

The bleeder circuit **1** includes a bipolar junction transistor (BJT) **10** and a bleeder circuit controller **11**. The controller **11** may be embodied as an integrated circuit. The BJT **10** comprises a collector terminal **12**, an emitter terminal **13** and a base terminal **14**. The controller **11** is connected to the base terminal **14**.

The collector terminal **12** is connected to the output of the bridge rectifier **7**. A collector resistor **15** is located between the collector terminal **12** and the bridge rectifier **7**. The resistor **15** is optional and may be provided to distribute thermal dissipation in the circuit **1** by shifting part of the total bleeder circuit dissipation from the BJT **10** to the resistor. In this way, the dissipation is physically distributed, so reducing cost for the thermal design. The emitter terminal **13** is configured to be connected to ground via an emitter resistor **16**.

The controller **11** is configured apply a control signal to the base terminal **14** to control the flow of a bleed current through the BJT **10**. Thus, the controller is configured to control the maximum bleed current. For this purpose, a voltage source **18** will be controlled to have a different value over time, depending on the type of dimmer detected by the controller (forward or backward phase cut) and the state of the dimmer (conductive state, non-conductive state, on-off transition, off-on transition). Thus, the bleeder circuit can respond to the operational state of the phase-cut dimmer over each of its cycles to ensure an appropriate bleed current is drawn by the bleed circuit **1** for correct operation of the dimmer **2**.

In lighting applications requiring compatibility with phase cut dimmers, current has to be drawn by the load during an off state of the dimmer to ensure that the dimmer functions properly. In addition to this off-state current, a certain "latching current" is required to complete a transition from an off-state to an on-state in the dimmer. Thus the bleeder circuit **1** operates together with the switched mode power supply **3** to draw this bleed current since the supply **3** cannot draw current from the dimmer **2** when it is in an off-state due to diode **21** and capacitor **22**.

The controller **11** further includes a variable current source **17** that is configured to set a maximum value of the current that can be supplied to the base terminal **14** as a function of the voltage measured at the base terminal **14**. The voltage source **18** is configured to output the control signal that is used to control the bleed current over the dimmer waveform. The voltage source is connected to an error determination element **19**. The error determination element **19** receives the control signal at one of its terminals and the measured signal indicative of current flow through the dimmer at its other terminal. In this embodiment the voltage at the base **14** provides the measured signal. The error determination element **19** controls a MOS transistor **20** by way of a connection to its gate, which in turn controls the current flow between the current source **17** and the base **14**.

Thus, when the momentary voltage of the rectified mains is high enough to prevent the BJT from saturating (i.e. when the collector voltage is higher than the base voltage), the bleed current will be determined by the output level of the voltage source **18**. A voltage drop across the base-emitter junction may be experienced. The voltage drop (Vbe) may be about 0.7V. The bleed current (Ibleed) may therefore be determined by the control signal and the resistance **16** such that Ibleed=(Vctrl−Vbe)/R16 where R16 is the resistance of emitter resistor **16**. In this mode of operation, error determination element **19**, acts as an error amplifier and together with transistor **20** it functions as a unity gain voltage buffer.

If the collector voltage drops below the base voltage the BJT saturates and the base current increases compared to that in the non-saturated mode of operation. So, without the current limit and if the controller would be capable of supplying an unlimited output current, a high current would flow from the internal IC supply of the controller to the base of the BJT. This is undesired for reason of inefficiency.

Thus, the controller is configured to limit the maximum current that can be conducted via transistor **20** into the base **14** of the BJT **10**. The limit on the current is set via current source **17** and is dependent on the measured signal indicative of current flow through the dimmer. In general, the measured signal comprises a measurement of current flow through the bleeder current. Ideally, the current limit is to be set to the value (or just above) of the actual dimmer current divided by the current gain factor (denoted by Hfe) of the BJT. In practice, a margin is taken into account to cover BJTs that have a lower Hfe than average. In this embodiment, as mentioned above, the base voltage is used as the measured signal and an appropriate function is determined.

FIG. **2** shows an example of the voltages and current waveforms for a forward phase cut dimmer. V_{rect} is the rectified voltage from the rectifier **7**, such as at point **23**. During a dimmer conduction period, the waveform is a phase cut sinusoidal mains voltage. During a dimmer non-conduction period, the voltage is low (typically a few volts) but not exactly zero, as will be appreciated by those skilled in the art. I_{Diode} is the current through diode **21** that flows for part of the cycle to charge the buffer capacitor **22**.

I_{bleed} shows an example bleeder current profile that may be used. Such a bleed current profile is achieved by control of the voltage "Vctrl" comprising the output from voltage source **18**, as will be described below. Thus, Vctrl comprises the control signal from voltage source **18**.

IB1 is the resulting base current if the base current is solely determined by voltage source **18** without using the current limit function provided by current source **17**. IB2 is the resulting base current if a fixed current limit is used, in this example 5 mA. IB3 is the base current when using the controller **1** as described in the above embodiment.

Prior to point **30**, the dimmer **2** is in a non-conduction state and the voltage at **23** is low. For an optimal behaviour of the phase cut dimmer **2**, the bleeder circuit **1** is required to keep the voltage low. This is achieved by the controller **11** setting Vctrl to a predetermined maximum value, which in this example is 3V. Thus, during the non-conduction period, the control signal voltage is set to an upper value.

The BJT **10** will try to draw a high emitter current due to the high control signal voltage setting but the voltage at **23** is low so the BJT **10** has a low collector **12** voltage and it will operate in saturated mode, resulting in a current flow though the bleeder circuit **1** that is determined by the impedance of the dimmer in non-conduction state. Obviously, in this interval, the precise waveform of IBleed depends on the construction of the dimmer. In such a saturated mode, rest of the BJT emitter current is supplied by the base-emitter current which would, in the absence of the current limit, be determined by the output of voltage source **18**, Vctrl, and emitter resistor **16** and would be drawn by the base of the BJT **10** and supplied through the transistor **20**. The operation of the current limit will be described in more detail below.

At point **30**, the dimmer starts its conduction phase. It is noted, that as soon as Vrect has stepped to a high value at the start of the conduction period, the base current IB1 drops significantly (by a factor equal to the BJT **10** current gain Hfe) because the operation mode of the BJT**10** has changed from saturated to non-saturated. The bleeder circuit **1** is initially configured to try and keep the voltage at **23** low as this will help the dimmer to latch. When the controller **11** has detected that the dimmer has started conducting, i.e at point **31**, and therefore that the current to the supply **3** via diode **22** is high enough to keep the dimmer conducting, the controller **11** is configured to ramp down the control signal, Vctrl.

Vctrl is regulated from point **32** onwards to the value required to keep the dimmer conducting. In this particular example, the Idiode current is higher than the holding current between **32** and **33**, hence Vctrl is lowered to a level such that the bleed current Ibleed is zero.

From point **33** onwards, the current I_{diode} is lower than the current required to keep the dimmer conducting (known as the holding current). The controller **11** is configured to gradually increase the voltage Vctrl of voltage source **18** such that the bleeder current complements the decreasing current through diode **22** to the required level. The BJT **10** operates in non-saturated mode.

At point **34**, the diode current I_{diode} has become zero. The control signal Vctrl is therefore constant to provide the holding current and the bleed current IBleed stabilizes to a fixed value.

Starting from point **35**, shortly before the mains zero crossing, the controller is configured to set Vctrl high thus placing the bleeder circuit in "high current mode", such that it is prepared to keep the voltage **23** low during the subsequent non-conduction period starting at point **36**.

At point **35**, the voltage **6** has dropped to a level where the BJT would again start to operate in saturated mode. As result, the base-emitter current IB1 would typically increase to a high value as shown in graph IB1. This is undesired because the current would come from a controller supply and so reduce power efficiency (regardless of supply arrangement). Thus, limiting the base-emitter current as a function of the base voltage allows the control signal to control the BJT to provide an effective bleeder circuit while limiting the base-emitter current at least when the dimmer is in a non-conduction period.

In a first example, the base current can be limited by setting the current source **17** to a fixed maximum value that is high enough to enable the controller to control the BJT to achieve the maximum desired bleeder current (120 mA in this example). For example, if the current gain Hfe of the BJT is at least 25, a current limit of about 5 mA is appropriate.

In a preferred example, the base current is controlled based on the measured bleeder circuit **1** current, which is indicative of the current through the dimmer **2**. This is achieved by measuring the base voltage and setting the current limit according to the function of FIG. **3**. In this example, the bleeder circuit current during the non-conduction period may be 10 mA. If we assume a worst-case current gain, Hfe, of for example 25, the base current can be limited to 0.4 mA. However, it is advantageous to set the maximum current limit higher than this for reliable operation. Thus, in this example, there is current limit margin included and the base current as shown in IB3 can be limited to a peak of 0.5 mA during the non-conduction period.

This control scheme enables the bleeder circuit to transition from pre-30 to post-30 region (off, non-conduction state to conduction-state of dimmer) without requiring a state-change detection or a change of the control voltage (Vctrl).

The operational principles described above for a forward phase cut dimmer apply equally to backward phase cut dimmers, with the necessary timing and magnitudes amended accordingly.

FIG. **3** shows an example of how the current limit set by current source **17** can be controlled depending on the voltage at the base **14**. The dashed line **40** shows the minimum current that needs to be available as function of the base voltage in order to drive the bleed current for a BJT **10** with a current gain, Hfe, of 25 and an emitter resistor **16** of, for example, 18 Ohms, while the BJT **10** is operating in an unsaturated mode. The dotted line **41** is the base current limit set by the current source **17** in the example where a static maximum current value of 5 mA is used. The solid line **42** shows an example current limit control function. The line **42** must be above the minimum current line **40** but for optimal efficiency, the current limit control function **42** should still be relatively close to the required minimum **40**. Thus the current control function includes a first region in which the current limit increases with the measured variable, which in this example is the voltage at the base, between a first threshold V1 and a second threshold V2. In this example, the current limit function increases linearly in the first region. The control function, in this example, has a second region defining a current maximum in which the current limit is held constant above the second threshold V2. The current control function may further include a third region in which the current limit is held constant, at an above zero value, while the base voltage is below the first threshold V1.

The invention claimed is:

1. A bleeder circuit controller configured to control a bipolar junction transistor having a collector configured to be connected to a rectified output of a phase cut dimmer to receive a bleed current, an emitter for connecting to ground, and a base, the bleeder circuit controller being configured to generate a control signal to control the bleed current through the bipolar junction transistor, to measure a signal indicative of the current flow through the dimmer, and to apply a current limit to a base-emitter current flow as a function of the measured signal,

wherein the function comprises a first region in which the base-emitter current limit increases with the measured signal between a first threshold and a second threshold.

2. The bleeder circuit controller of claim **1**, wherein the signal indicative of the current flow through the dimmer comprises at least one of:

a voltage at the base of the bipolar junction transistor;

a voltage at the emitter of the bipolar junction transistor;

a voltage at the collector of the bipolar junction transistor; and

a rectified phase cut mains voltage, the mains voltage comprising the voltage applied to an input of the phase cut dimmer.

3. The bleeder circuit controller of claim **1**, wherein the controller is configured to control the bipolar junction transistor by applying the control signal at the base for controlling the bleed current from the phase-cut dimmer through the bipolar junction transistor.

4. A bleeder circuit controller as defined in claim **3**, further comprising a voltage source that is configured to generate said control signal.

5. The bleeder circuit controller of claim **3**, wherein the controller is configured to control the current of the control signal as a function of the measured signal to provide said current limit.

6. The bleeder circuit controller of claim **5**, wherein the controller comprises a transistor configured to control the flow of current to the base of the bipolar junction transistor.

7. The bleeder circuit controller of claim **5**, wherein the controller is configured to provide a current limit control signal for controlling a controllable impedance connected to the emitter to control the flow of current from the controller to the base of the bipolar junction transistor.

8. The bleeder circuit controller of claim **1**, wherein the control signal generated by the controller is configured to control the bleed current to provide:

an off-state current during an off-state of the phase-cut dimmer;

a latching current required for the phase-cut dimmer to transition between an off-state and an on-state;

a holding current required to maintain the phase-cut dimmer in an on-state once it is in said on-state; and

a discharge current for backward phase cut dimmers to pull the dimmer output voltage low at the transition between an on-state and an off-state.

9. The bleeder circuit controller of claim **1**, wherein the controller comprises an error determination element configured to compare a voltage of the control signal with a measured voltage at the base and control the base-emitter current flow using said comparison.

10. The bleeder circuit controller of claim **1**, wherein the function further comprises a second region defining a maximum current in which the current limit is held constant when the measured signal exceeds the second threshold.

11. The bleeder circuit controller of claim **1**, wherein the function is configured to limit the base-emitter current such that the controller, when in use, drives the bipolar junction transistor in a linear operation mode substantially on an edge of a saturation mode.

12. The bleeder circuit controller of claim **1**, wherein the bipolar junction transistor is arranged to be cascaded with a metal oxide semiconductor (MOS) transistor, the collector of the bipolar junction transistor being connected to a source of MOS transistor, the drain of the MOS transistor being connected to a rectified mains signal, and the gate of the MOS transistor being connected to a fixed voltage source.

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